Enchanced Torque Controlled Balancing through Multimodal Sensor Fusion based on an Extended Kalman Filter

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1 Introduction

Towards achieving dynamic humanoid robots that can function effectively in our unstructured environments, incorporation of some form of mechanical compliance and whole-body torque control present a very promising approach. However, one of the primary limitations affecting this approach is that of accurate, and effective state information, in particular, that of estimation of external forces that influence the body. Despite the presence of a rich suite of sensors in modern bipedal humanoid robots such as the *iCub*, a computationally efficient framework for real-time state estimation is still and open challenge. In this paper, we tackle a crucial subproblem of the walking and balancing challenge, that of accurate estimation of foot state and contact wrenches, in order to suitably facilitate torque-controlled balancing on compliant (soft) surfaces. Our approach, based on an Extended Kalman Filter (EKF), estimates the foot state as well as the wrenches it is subject to, in real-time. This estimation framework is then combined with the dynamic control task of torque-controlled balancing on a compliant surface introduced by a distributed tactile sensor (skin). We believe that this approach is an appropriate strategy towards enhancing the capability of torque-controlled humanoids in coping with uneven and compliant terrains.

2 The Problem

Whole-body control on the iCub is done by regulating forces on rigid noncoplanar contacts as extensively described in [2]. The current state-of-the-art with this approach is in stable balancing on rigid surfaces (as seen in Fig. 1), even in the face of unpredicted disturbances.

In this framework mentioned above two important assumptions are made. It first is that the feet are in rigid contact with the ground while the second is that direct contact force feedback cannot be utilized currently. Now in order to be suitably dynamic in the interactions with an unstructured environment, the approach of incorporating mechanical compliance at the contact, such as a flexible skin can prove useful. Although troublesome for the control, a compliant skin would allow more sensitive pressure and tactile sensing on the interaction with the surface, in addition to better coping ability with imperfections in terrain flatness. The compliance also provides natural advantages in impact absorption in dynamic walking. Such a compliant surface can also be incorporated with sensing elements to provide an additional source of sensory information that can be used along with the F/T sensors in the feet for proper feedback [1]. Nevertheless, a compliant skin fundamentally violates the primary assumption of rigid contacts due to deformation of the interface and thus can cause major problems for a torque controlled balancing strategy.

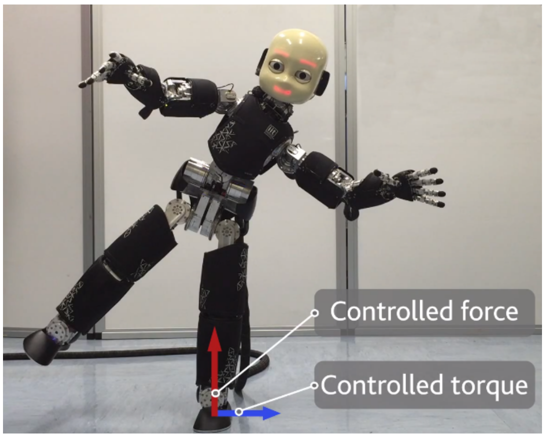

Figure 1: Torque-controlled balancing of the iCub humanoid robot under rigid ground contact conditions.

Regarding the second assumption of non-usage of direct contact force feedback, this is necessitated due to a diminished level of confidence on the force/torque sensors measurements. In particular, miscalibrations and non-linearities represent a challenge, that become apparent with the kind of motions the robot does when standing on double and particularly single support (when all the weight of the robot is supported by a single F/T sensor). This issue is not unique to the icub platform and affects many existing humanoids incorporating some kind of F/T sensing. For this reason, the work presented in [2] instead of closing the loop on the force/torque sensors, computes feed-forward model-based contact wrenches, which in turn are utilized within the balancing control strategy.

This the key problem that is to be tackled is accurate (and real-time) estimation of the pose of the feet of the robot, considering unknown deformations of the compliant interface, as well as, accurate fusion and estimation of the wrenches that the feet are subjected to - both internally from within the robot, and externally from the world.

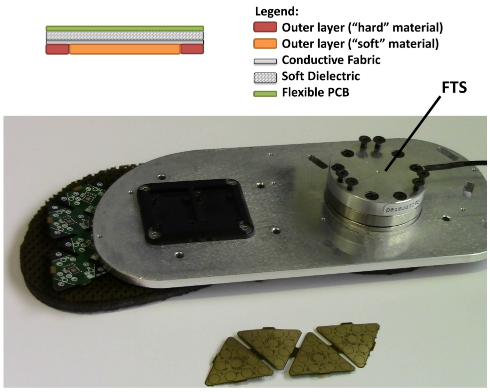

Figure 2: The compliant tactile (skin) sensors on the sole of the robot feet.

3 The Approach

The approach we used for a reliable real-time estimation of external contact wrenches and feet pose consisted of an augmented quaternion-based Extended Kalman Filter (EKF); *Augmented* because the input to the system, i.e. the external wrenches, are incorporated into the state vector and *quaternion-based* because of the choice of quaternion parameterisation for expressing the orientation (pose of the foot). While the former allows direct estimation of the wrenches as a result of filtering, the latter avoids the singularity problems associated with simpler parameterizations like Euler angles. Also the compliant sensory skin provides an additional measurement of contact wrenches after proper estimation of its stiffness matrix and corresponding covariance matrix through a Maximum Likelihood Estimation method.

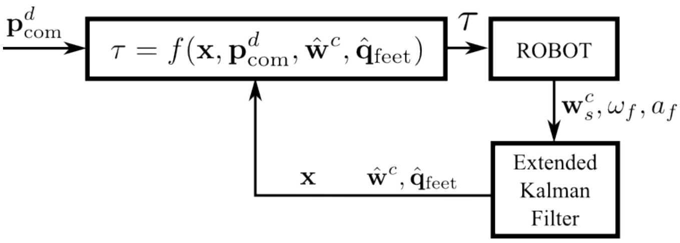

Figure 3: A schematic of the estimation and balancing control framework.

Figure 3 is a schematic of the complete estimation and control framework. Here the balancing controller is a function of robot state $\mathbf{x}$, the desired state of the center of mass $\mathbf{p}^d_{\text{com}}$, the estimated contact wrenches $\hat{\mathbf{w}}$ and the estimated orientation of the feet $\hat{\mathbf{q}}_{\text{feet}}$. The output torques are sent to the robot, while the set of sensor data, such as angular speed of the feet from the gyroscope readings ω_f, skin-based contact wrench $\mathbf{w}^c_s$ and orientation of the nominal gravity vector a_f provided by the accelerometer are inputs and measurements to the EKF. This in turn computes real-time estimates that are used within the controller for the balancing task.

4 Experiments and Results

We test the proposed approach on a balancing control scenario on the iCub robot while incorporating the compliant skin. The results indicate that the approach not only facilitates balancing in the face of compliant ground contact, but also allows improvements in balancing control due to the improved F/T estimates of external (contact) wrenches.

References

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